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Dated. 14 OCTOBER 2003

# PCT

## REQUEST

The undersigned requests that the present international application be processed according to the Patent Cooperation Treaty.

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PCT/GB 2003 / 0 0 2 5 3 9

International Application No.

3 JUNE 2003

International Filing Date 13-06-03

United Kingdom Patent Office PCT International Application

Name of receiving Office and "PCT International Application"

Applicant's or agent's file reference (if desired) (12 characters maximum) GML2764

**Box No. I TITLE OF INVENTION**

ICE DETECTION APPARATUS AND METHOD

**Box No. II APPLICANT** ☐ This person is also inventor

Name and address: *(Family name followed by given name; for a legal entity, full official designation. The address must include postal code and name of country. The country of the address indicated in this Box is the applicant's State (that is, country) of residence if no State of residence is indicated below.)*

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This person is applicant for the purposes of: ☐ all designated States ☒ all designated States except the United States of America ☐ the United States of America only ☐ the States indicated in the Supplemental Box

**Box No. III FURTHER APPLICANT(S) AND/OR (FURTHER) INVENTOR(S)**

Name and address: *(Family name followed by given name; for a legal entity, full official designation. The address must include postal code and name of country. The country of the address indicated in this Box is the applicant's State (that is, country) of residence if no State of residence is indicated below.)*

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☐ applicant only

☒ applicant and inventor

☐ inventor only *(If this check-box is marked, do not fill in below.)*

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☒ Further applicants and/or (further) inventors are indicated on a continuation sheet.

**Box No. IV AGENT OR COMMON REPRESENTATIVE; OR ADDRESS FOR CORRESPONDENCE**

The person identified below is hereby/has been appointed to act on behalf of the applicant(s) before the competent International Authorities as: ☒ agent ☐ common representative

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Sheet No. ...4...

**Continuation of Box No. III FURTHER APPLICANT(S) AND/OR (FURTHER) INVENTOR(S)**

*If none of the following sub-boxes is used, this sheet should not be included in the request.*

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- [x] applicant and inventor
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This person is applicant for the purposes of:
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- [x] applicant and inventor
- [ ] inventor only *(If this check-box is marked, do not fill in below.)*

Applicant's registration No. with the Office

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State *(that is, country)* of residence: Greece

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Name and address: *(Family name followed by given name; for a legal entity, full official designation. The address must include postal code and name of country. The country of the address indicated in this Box is the applicant's State (that is, country) of residence if no State of residence is indicated below.)*

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- [ ] inventor only *(If this check-box is marked, do not fill in below.)*

Applicant's registration No. with the Office

State *(that is, country)* of nationality: Greece

State *(that is, country)* of residence: Greece

This person is applicant for the purposes of:
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Name and address: *(Family name followed by given name; for a legal entity, full official designation. The address must include postal code and name of country. The country of the address indicated in this Box is the applicant's State (that is, country) of residence if no State of residence is indicated below.)*

This person is:
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- [ ] inventor only *(If this check-box is marked, do not fill in below.)*

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**Box No. V DESIGNATION OF STATES** *Mark the applicable check-boxes below; at least one must be marked.*

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**Box No. VI PRIORITY CLAIM**

The priority of the following earlier application(s) is hereby claimed:

| Filing date of earlier application *(day/month/year)* | Number of earlier application | Where earlier application is: national application: country or Member of WTO | regional application:* regional Office | international application: receiving Office |
|---|---|---|---|---|
| item (1) | NONE | | | |
| item (2) | | | | |
| item (3) | | | | |
| item (4) | | | | |
| item (5) | | | | |

☐ Further priority claims are indicated in the Supplemental Box.

The receiving Office is requested to prepare and transmit to the International Bureau a certified copy of the earlier application(s) *(only if the earlier application was filed with the Office which for the purposes of this international application is the receiving Office)* identified above as:

☐ all items ☐ item (1) ☐ item (2) ☐ item (3) ☐ item (4) ☐ item (5) ☐ other, see Supplemental Box

* *Where the earlier application is an ARIPO application, indicate at least one country party to the Paris Convention for the Protection of Industrial Property or one Member of the World Trade Organization for which that earlier application was filed (Rule 4.10(b)(ii)):* ....

......................................................................

**Box No. VII INTERNATIONAL SEARCHING AUTHORITY**

Choice of International Searching Authority (ISA) *(if two or more International Searching Authorities are competent to carry out the international search, indicate the Authority chosen; the two-letter code may be used)*:

ISA / ......................................................................

Request to use results of earlier search; reference to that search *(if an earlier search has been carried out by or requested from the International Searching Authority)*:

Date *(day/month/year)* Number Country *(or regional Office)*

**Box No. VIII DECLARATIONS**

The following declarations are contained in Boxes Nos. VIII (i) to (v) *(mark the applicable check-boxes below and indicate in the right column the number of each type of declaration)*: Number of declarations

| | | | |
|---|---|---|---|
| ☐ | Box No. VIII (i) | Declaration as to the identity of the inventor | : |
| ☐ | Box No. VIII (ii) | Declaration as to the applicant's entitlement, as at the international filing date, to apply for and be granted a patent | : |
| ☐ | Box No. VIII (iii) | Declaration as to the applicant's entitlement, as at the international filing date, to claim the priority of the earlier application | : |
| ☐ | Box No. VIII (iv) | Declaration of inventorship (only for the purposes of the designation of the United States of America) | : |
| ☐ | Box No. VIII (v) | Declaration as to non-prejudicial disclosures or exceptions to lack of novelty | : |

Sheet No. ...5... PCT/GB 2003 / 0 0 2 5 3 9

**Box No. IX CHECK LIST; LANGUAGE OF FILING**

This international application contains:
(a) in paper form, the following number of sheets:

| | | |
|---|---|---|
| request (including declaration sheets) | : | 5 |
| description (excluding sequence listings and/or tables related thereto) | : | 12 |
| claims | : | 4 |
| abstract | : | 1 |
| drawings | : | 10 |
| Sub-total number of sheets | : | 32 |
| sequence listings | : | |
| tables related thereto | : | |
| *(for both, actual number of sheets if filed in paper form, whether or not also filed in computer readable form; see (c) below)* | | |
| Total number of sheets | : | 32 |

(b) ☐ only in computer readable form (Section 801(a)(i))
 (i) ☐ sequence listings
 (ii) ☐ tables related thereto
(c) ☐ also in computer readable form (Section 801(a)(ii))
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Type and number of carriers (diskette, CD-ROM, CD-R or other) on which are contained the
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☐ tables related thereto: ................
*(additional copies to be indicated under items 9(ii) and/or 10(ii), in right column)*

This international application is accompanied by the following item(s) *(mark the applicable check-boxes below and indicate in right column the number of each item)*: Number of items

1. ☐ fee calculation sheet :
2. ☐ original separate power of attorney :
3. ☐ original general power of attorney :
4. ☐ copy of general power of attorney; reference number, if any: ................ :
5. ☐ statement explaining lack of signature :
6. ☐ priority document(s) identified in Box No. VI as item(s): ................ :
7. ☐ translation of international application into *(language)*: ................ :
8. ☐ separate indications concerning deposited microorganism or other biological material :
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11. ☐ other *(specify)*: ................ :

Figure of the drawings which should accompany the abstract: 3

Language of filing of the international application: ENGLISH

**Box No. X SIGNATURE OF APPLICANT, AGENT OR COMMON REPRESENTATIVE**

*Next to each signature, indicate the name of the person signing and the capacity in which the person signs (if such capacity is not obvious from reading the request).*

LOMAS Geoffrey Michael
Professional Representative

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1. Date of actual receipt of the purported international application: 13 JUNE 2003 13-06-03
2. Drawings: ☒ received: ☐ not received:
3. Corrected date of actual receipt due to later but timely received papers or drawings completing the purported international application:
4. Date of timely receipt of the required corrections under PCT Article 11(2):
5. International Searching Authority (if two or more are competent): ISA /
6. ☒ Transmittal of search copy delayed until search fee is paid

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13 June 2003

Dear Madam

**New International PCT Application**
**Aerospace Composite Technologies Ltd**

Please find enclosed the following documents for a new PCT application as indicated above.

- ☒ Form PCT/RO/101 – 5 pages
- ☒ Specification
- ☒ Drawings (x 10 sheets)

Confirmation of this faxed transmission will follow when requested.

Fees will be forwarded in due course.

Yours faithfully

Barker Brettell

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# ICE DETECTION APPARATUS AND METHOD

The present invention relates to apparatus and methods for detecting and monitoring ice accretion, and in particular, but not exclusively, on aircraft surfaces.

Ice accretion on flying surfaces affects the aerodynamic performance and handling qualities of an aircraft, and may require different pilot corrective action, dependent upon the surface that ice is accreting onto. Current methodology for ice detection usually relies on an indirect method, normally based on ambient air temperature, and liquid water content. When a pre-set threshold level is reached, the ice protection system is activated, whether or not ice is accreting on critical surfaces. This method is not cost effective or efficient for an ice protection system.

Known ice sensor arrangements are capable of detecting the presence, and with some the thickness, of ice, however they all offer challenges for integration into a distributive network. Furthermore the known ice sensor arrangements do not give an indication of the type (or roughness) of ice accretion, which has a marked influence on the aerodynamic performance of an aircraft.

The present invention seeks to provide an alternative ice detection apparatus and method.

According to a first aspect of the invention there is provided apparatus for detecting ice accretion comprising an electromagnetic radiation emitter and an array of sensors, the emitter being located intermediate of the array of sensors and at least some of the sensors being located at different distances from the emitter.

Most preferably the sensors are substantially symmetrical about the emitter.

Preferably the sensor array comprises first and second sets of sensors which are arranged in generally opposing respective paths away from the emitter.

Preferably the sets of sensors are arranged in respective straight lines. Alternatively the sets of sensors may be arranged to follow respective curvilinear paths which may be (mirror) symmetrical about the emitter.

The apparatus may comprise third and fourth sets of sensors which are arranged to follow (generally opposing) respective paths generally away from the emitter. Preferably the first and second sets of sensors, and the third and fourth sets of sensors together form a substantially cruciform arrangement of sensors about the emitter.

According to a second aspect of the invention there is provided a method of monitoring ice accretion comprising emitting an electromagnetic radiation signal from an emitter, detecting radiation which is scattered and/or reflected by a layer of accreted ice, detection of the scattered and/or reflected radiation being effected by an array of sensors, at least some of the sensors being at different distances from the emitter, and comparing the detected intensity of radiation at different distances from the emitter to respective predetermined values so as to determine the type of accreted ice.

Preferably the method comprises determining the thickness of ice which has accreted on an aircraft surface.

Preferably the method comprises determining the type of ice which has accreted on an aircraft surface.

The method desirably comprises comparing the detected spatial distribution of intensity of the reflected and/or scattered radiation to stored data representative of the spatial distribution of intensity of the reflected and/or scattered radiation for different ice types.

According to a third aspect of the invention there is provided data processing equipment for ice detection apparatus comprising comparator means, the comparator means, in use, receiving signals representative of the intensity of radiation scattered and/or reflected by a layer of accreted ice, which scattered and/or reflected radiation is detected by an array of sensors, at least some of the sensors being located at different distances from an electromagnetic radiation emitter, the comparator means being configured to compare the values of detected intensity to predetermined values and determine whether said values of detected intensity are above predetermined values so as to enable the data processing equipment to determine the type of accreted ice.

Various embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 is a schematic representation of an ice detection apparatus for an aircraft;

Figure 2 is a schematic representation of part of the ice detection apparatus of Figure 1 which shows reflected and scattered light from an accreted layer of ice;

Figure 3 is a cross-sectional view of aircraft surface which is provided with flush mounted fibre optic cables;

Figure 4 is a schematic plan view of an array of sensors disposed diametrically about a central emitter;

Figure 5 is a schematic plan view of a second array of sensors which are arranged in a cruciform about a central emitter;

Figure 6 shows a schematic plan view of a third array of sensors which are arranged at various angles to the skin of an aircraft;

Figure 7 shows curves of intensity against sensor position for different ice types;

Figure 8 shows curves of intensity against ice thickness for different ice types;

Figure 9 is a schematic perspective view of a diode emitter and sensor head;

Figure 10 is a plan view of the diode emitter and sensor head shown in Figure 9;

Figure 11 is a schematic perspective view of a rotorcraft blade and associated equipment, the blade being provided with multiple emitter and sensor arrangements,

Figure 12 is a schematic representation of the electronic components of the data acquisition unit of the ice detection apparatus of Figure 1,

Figure 13 is a truth table showing how the possible various outputs of the comparators correspond to different ice types, and

Figure 14 is an alternative emitter/sensor configuration.

With reference to Figure 1 there is shown an apparatus 1 for monitoring ice accretion on an aerofoil 9, which apparatus comprises a light emitter 10, and sensors 3, 4, 5, 6, 7 and 8.

As is seen from Figure 3, the ice monitoring region 2 of the aerofoil 9 comprises the emitter 10 which comprises central fibre optic cable, and six sensors 3, 4, 5, 6, 7 and 8 which are provided by single mode fibre optic cables disposed diametrically about the emitter 10. The emitter 10 and the sensors 3, 4, 5, 6, 7 and 8 are accommodated in respective holes 16 which have been drilled into the aerofoil 9. The emitter and sensors are flush mounted (ie air conformal) with the outer surface 17 of the aerofoil 9. The distance between the longitudinal axes of adjacent sensors, and between the longitudinal axis of the emitter 10 and the longitudinal axes of the sensors 5 and 6 is 1 mm.

The apparatus 1 further comprises ambient light filters 11 which receive optical signals from the sensors 3, 4, 5, 6, 7 and 8. The signals from the filters are then received by a diode array 12 which converts the optical signals into electrical signals. The output of the diode array 12 is then fed into a data acquisition unit 13 and the output from the data acquisition unit 13 to a control unit 14.

The data acquisition unit 13 is configured to determine ice thickness and type, and to better understand the structure of this unit some explanation of various types is now given.

Glaze/Clear ice, as it name suggests, is optically clear and very little light is scattered.

Rime ice, is optically opaque, it scatters light much further from a source than clear ice.

Mixed phase ice, as its name suggests if anything in between, to the amount of scattering of light is dependent upon the content of glaze and rime ice.

In the case of rime ice growth, and for small thickness of ice, the dominant contributions to the optical signal detected by the fibres are due to light scattered from the proximal irregular ice-air interface, giving rise to a rapidly increasing signal with ice thickness. However, as the ice thickness increases, and the ice-air interface recedes away from the fibre facets a reduction in the optical contribution of the ice-air interface is caused and scattering from the main ice volume become more significant resulting in a slower rate of increase in intensity with ice thickness. In rime ice all fibres, on both sides of the light source, exhibit similar behaviour but at reduced signal strength (with increasing distance away from the light source) due to the regular optical diffusion.

In the case of glazed or clear ice, which is transparent and has a very irregular structure, with pointed ice-air interfaces and micro-cracks, light is randomly reflected or scattered therefrom. Consequently for small ice thickness, the dominant contribution to the optical signal detected by the fibres, is due to the random reflections and scattering from the volume and surface irregularities. However as the ice thickness increases the surface irregularities can potentially contribute to the optical signal, as the ice is mostly transparent, but these contributions are random, and scattering from the ice volume micro-cracks dominate. The

characteristic optical signature, detected by the fibre optics during the ice growth of this type of ice, exhibits a general increase of the optical signal with ice thickness with large fluctuations related to the random scattering at the ice air interfaces.

Figure 7 shows three curves 90a, 90b, 90c of detected intensity against sensor position. The curve 90a represents the 'spatial signature' of glazed or clear ice, the curve 90b represents the 'spatial signature' of mixed phase ice, and the curve 90c represents the 'spatial signature' of rime ice.

Referring to Figure 8 there is shown a family of curves 91a, 91b, 91c and 91d of detected intensity (measured at a particular distance from the emitter) against ice thickness. The curve 91d is representative of rime ice, and the curve 91a is representative of glazed or clear ice. The curves 91b and 91c are representative of mixed phase ice types, with the curve 91c representing ice having a greater rime ice content than the ice which is represented by curve 91b.

The data acquisition unit 13 is shown in more detail in Figure 12. The unit 13 comprises three comparators COMP1, COMP2 and COMP3, a logic array 100, an analogue to digital converter 95, a memory map 96 and a digital to analogue converter 97.

One input of each of the comparators COMP1, COMP2 and COMP3 is connected to the outputs of operational amplifiers OPAMP1, OPAMP2 and OPAMP3 respectively. The operational amplifiers OPAMP1, OPAMP2 and OPAMP3 are provided with feedback resistors R1, R2 and R3 respectively, and input resistors R4 and R5, R6 and R7, and R8 and R9 respectively. The input resistors are connected to the photodiodes PD1, PD2, PD4, PD5 and PD6, which receive signals from the

respective optical fibres of each of the sensors 5, 6, 4, 7, 3 and 8 respectively. Operational amplifier OPAMP1 receives input from PD1 and PD2, operational amplifier OPAMP2 receives input from PD3 and PD4, and operational amplifier OPAMP3 receives input from PD5 and PD6.

Outputs of the comparators COMP1, COMP2 and COMP3 are connected to a logic array 100 which comprises two exclusive-OR gates 101 and 102 and two AND gates 103 and 104.

The eight bit analogue to digital converter 95 receives an input from OPAMP1 and the output of the converter 95 is connected to the memory map 96, as is the output of the logic array 100. The memory map 96 has stored therein look-up tables representative of detected intensity values and corresponding ice thickness values for various ice types as detected by sensors 5 and 6 (ie those sensors closest to the emitter 10). These values in the look-up tables are based on the various curves shown in Figure 8.

The output of the memory map 96 is input into a digital to analogue converter 97 which produces an output 98.

In use the apparatus 1 operates as follows. Radiation in the wavelength range 820 mm to 850 mm is generated by light source 11 and emitted from the distal end of the emitter 10 which is arranged to be substantially flush with the outer surface 17 of the aerofoil 9. The light issuing from the emitter 10 is directed generally outwardly of the outer surface 17. As best seen in Figure 2 light enters a layer 15 of accreted ice on the aerofoil 9, some of the light is reflected back towards the aerofoil at the boundary 20 between the accreted ice and the air 21. Some of the emitted light is scattered by the ice layer 15 back towards the aerofoil 9.

That reflected and scattered light is received by the flush-mounted distal ends of the sensors 3, 4, 5, 6, 7 and 8.

The signals from the photodiodes PD1, PD2, PD3, PD4, PD5 and PD6 are amplified by operational amplifiers OPAMP1, OPAMP2 and OPAMP3, the outputs of which are input to the respective comparators. As can be seen from Figure 12, one input of each comparator COMP1, COMP2 and COMP3 is held at a threshold voltage. In particular one input of COMP1 is held at a threshold voltage determined by R4 and R5, one input of COMP2 is held at a threshold voltage by R6 and R7, and one input of COMP3 is held at a voltage determined by R8 and R9. The respective threshold voltages are determined in accordance with the data from Figure 7. If an (amplified) signal from connected photodiodes exceeds the threshold voltage then the comparator outputs a '1', otherwise the comparator issues an '0'. The outputs of the comparators are input into the logic array 100, the logic array being configured to implement the truth table shown in Figure 13. Thus a two-bit output 99 results which is indicative of the type of the accreted ice layer. In the truth table:

| | | |
|---|---|---|
| 00 | - | No ice |
| 01 | - | glaze/clear ice |
| 10 | - | mixed phase ice |
| 11 | - | rime ice |

As is evident if comparators COMP3 and/or COMP2 output a '1' this indicates wider scattering.

The thickness of the accreted ice layer 15 is determined in the following way. Returning to Figure 12, it can be seen that the output of OPAMP1 is fed to the analogue to digital converter 95. This signal provides a non-linear measurement of ice thickness. Since ice type has been

determined, and is given by output 99, the appropriate look-up table stored in memory map 96 can be selected. It is then a straightforward operation to locate in the appropriate look-up table the detected intensity value input by the converter 95 and read the corresponding ice thickness value. The converter 97 then converts that value into an analogue signal 98.

Signals from the data acquisition unit 13 are then fed to the control unit 14. The control unit uses the signals from the data acquisition unit 13 to apply power to the aircraft ice protection system (IPS).

The way the IPS is configured will be dependent upon the application of the sensors. With a single sensor system, the control unit will apply an algorithm to determine the required de-icing sequence given the current conditions. A multi-sensor system on the other hand has the capability to apply the de-icing sequence dependent upon the specific ice build up at that point on the airframe/airfoil.

A further simplified use of the apparatus 1 would be to provide an 'ice/no ice' indication. This would be useful to the pilots of smaller general aviation aircraft without ice protection systems fitted, to allow for easier identification of wing or tail stall due to ice accretion.

With reference to Figure 11 there is shown a helicopter blade 25 which is provided emitter/sensor configurations 26, 27, 28, 29 and 30 which are arranged to monitor ice accretion along the length of leading edge 31 of the blade 25.

Each emitter/sensor configuration comprises a central emitter (unreferenced) in the form of a fibre optic cable which interposes two diametrically opposed sensors (unreferenced) also provided by fibre optic

cables. Each emitter/sensor configuration is arranged to monitor a respective zone of the blade 25. The fibre optic cables, which would typically be embedded in the blade, are arranged to lead to the inboard end of the blade 25 to pre-amp and link electronics 32. A link 33 comprises an optical slip ring which allows the sensed data to pass from the rotating blade 25 to the frame of the aircraft. The aircraft then houses an optic module 34 and computer and control electronics 35.

This 'distributive architecture' opens up the possibility for multiple ice protection technologies to be used on the same aircraft in different areas.

There are numerous other ways in which the invention could be embodied. In one preferred embodiment the emitter and sensors are provided as an integral unit in the form of an emitter/sensor head which may be installed into an aircraft by making a suitably sized recess therein. Signals would be sent back to remotely located data processing equipment.

In yet a further embodiment shown schematically in Figures 9 and 10, an emitter/sensor head may comprise an array of photodiodes (which serve as sensors) 41 to 50 and a central light emitting diode 40.

With reference to Figure 5 there is shown an alternative emitter/sensor arrangement 70 wherein fibre optic cables 73 are arranged in two sets of sensors, one on each side of a light emitting fibre optic cable 72, and fibre optical cables 71 are arranged in two similar sets about cable 72, but at substantially 90° relative thereto. It will be appreciated that the centre spacings between adjacent cables 71 and adjacent cables 73 need not necessarily be the same, so

PCT/GB 2003 / 0 0 2 5 3 0



$x_1$ = or ≠ $x_2$ = or ≠ $x_n$, and

$y_1$ = or ≠ $y_2$ = or ≠ $y_n$

This cruciform arrangement not only increases the detection area, but also provides a degree of redundancy in the arrangement.

Figure 6 illustrates that emitter and/or sensor cables 80 and 81 need not necessarily extend substantially perpendicular to the outer surface of the aircraft, and moreover, $\theta_1$ = or ≠ $\theta_n$ or ≠ Ø.

The spacing between the centres of adjacent optical fibres could typically be in the range 40$\mu$m to 5 mm, for example.

Figure 14 shows an alternative emitter/sensor configuration which comprises an emitter 110 and a plurality of sensors 111. The sensors 111 are arranged in a substantially spiral path around the intermediately located emitter 110, and accordingly the sensors are located at progressively greater distances from the emitter 110.

PCT/GB 2003 / 0 0 2 5 3 9



## CLAIMS

1. Apparatus for detecting ice accretion comprising an electromagnetic radiation emitter (10) and an array of sensors (3, 4, 5, 6, 7, 8), the emitter being located intermediate of the array of sensors and at least some of the sensors being located at different distances from the emitter.

2. Apparatus as claimed in claim 1 in which the sensors (3, 4, 5, 6, 7, 8) are substantially symmetrical about the emitter (10).

3. Apparatus as claimed in claim 1 or claim 2 in which the array of sensors (3, 4, 5, 6, 7, 8) comprises a first set of sensors (3, 4, 5) and a second set (6, 7, 8) of sensors, the first and second sets of sensors being arranged to follow respective paths generally away from the emitter (10).

4. Apparatus as claimed in claim 3 in which the sets of sensors (3, 4, 5, 6, 7, 8) are arranged in respective radial paths.

5. Apparatus as claimed in claim 3 in which the array of sensors further comprises third (71) and fourth (71) sets of sensors, the first, second, third and fourth sets of sensors together forming a substantially cruciform arrangement of sensors about the emitter (10).

6. Apparatus as claimed in any preceding claim in which the array of sensors (3, 4, 5, 6, 7, 8) is substantially flush with a surface (17) in which the array is mounted.

7. Apparatus as claimed in any preceding claim which is an apparatus for detecting ice accretion (15) on an aircraft surface (9, 17).

8. A method of monitoring ice accretion comprising emitting an electromagnetic radiation signal from an emitter (10), detecting radiation which is scattered and/or reflected by a layer of accreted ice, detection of the scattered and/or reflected radiation being effected by an array of sensors (3, 4, 5, 6, 7, 8), at least some of the sensors being at different distances from the emitter, and comparing the detected intensity of radiation at different distances from the emitter to respective predetermined values so as to determine the type of accreted ice.

9. A method as claimed in claim 9 which comprises determining whether the detected intensity of radiation at a particular distance from the emitter is above a predetermined threshold value.

10. A method as claimed in claim 8 or claim 9 which comprises determining the type of accreted ice in response to which sensors at different distances from the emitter detect scattered and/or reflected intensity above respective predetermined threshold values.

11. A method as claimed in claim 8, claim 9 or claim 10 which comprises selecting a look-up table of detected intensity values and ice thickness values in response to the determined ice type.

12. A method as claimed in claim 11 which comprises determining ice thickness by locating a value of ice thickness in the respective look-up table which corresponds to a detected intensity at a particular distance from the emitter (10).

13. A method as claimed in claim 12 which comprises using the value of detected intensity which corresponds to a sensor position which is closest to the emitter to determine the ice thickness from the look-up table.

14. Data processing equipment (13) for ice detection apparatus (1) comprising comparator means (COMP1, COMP2, COMP3), the comparator means, in use, receiving signals representative of the intensity of radiation scattered and/or reflected by a layer of accreted ice (15) which scattered and/or reflected radiation is detected by an array of sensors (3, 4, 5, 6, 7, 8), at least some of the sensors being located at different distances from an electromagnetic radiation emitter (10), the comparator means being configured to compare the values of detected intensity to predetermined values and determine whether said values of detected intensity are above the predetermined values so as to enable the data processing equipment to determine the type of accreted ice.

15. Data processing equipment as claimed in claim 14 in which the comparator means (COMP1, COMP2, COMP3) is configured to compare detected intensity at different distances from the emitter (10) to respective predetermined values.

16. Data processing equipment as claimed in claim 15 in which the comparator means (COMP1, COMP2, COMP3) comprises multiple comparators, each comparator being input with a signal which is representative of a detected intensity at a respective distance from the emitter (10).

17. Data processing equipment as claimed in claim 16 in which each comparator (COMP1, COMP2, COMP3) is configured to compare a received detected intensity to a respective threshold value.

18. Data processing equipment as claimed in claim 17 in which outputs of the comparators (COMP1, COMP2, COMP3) are indicative of the type of the accreted ice.

19. Data processing equipment as claimed in claim 18 in which the outputs of the comparators (COMP1, COMP2, COMP3) are input into a logic array (100), the logic array being configured to output a binary number which is indicative of the type of the accreted ice.

20. Data processing equipment as claimed in any of claims 13 to 19 which comprises a memory (96) which stores look-up tables of detected intensity values and corresponding ice thickness values for different ice types.

21. Data processing equipment as claimed in claim 20 which is configured to select a look-up table in response to the determined ice type.

22. Data processing equipment as claimed in claim 21 which is configured to determine ice thickness by locating an ice thickness value in the look-up table which corresponds to a detected intensity.

PCT/GB 2003 / 0 0 2 5 3 9




## ABSTRACT

### ICE DETECTION APPARATUS AND METHOD

Ice detection apparatus (1) for monitoring ice accretion on aircraft surfaces, comprising an array of optical fibres (3, 4, 5, 6, 7 and 8) which are mounted flush with an outer surface (17) of an aircraft skin (9), and an intermediately located electromagnetic radiation emitter (10) which is provided by an optical fibre. In use radiation is emitted by the emitter generally outwardly of the aircraft surface, and the layer of accreted ice (15) scatters and reflects the emitted radiation. The scattered and/or reflected radiation is detected by the sensors, and the spatial distribution of the detected radiation intensity about the emitter can be used to calculate the thickness of the layer of ice and the type of ice.

FIGURE 3

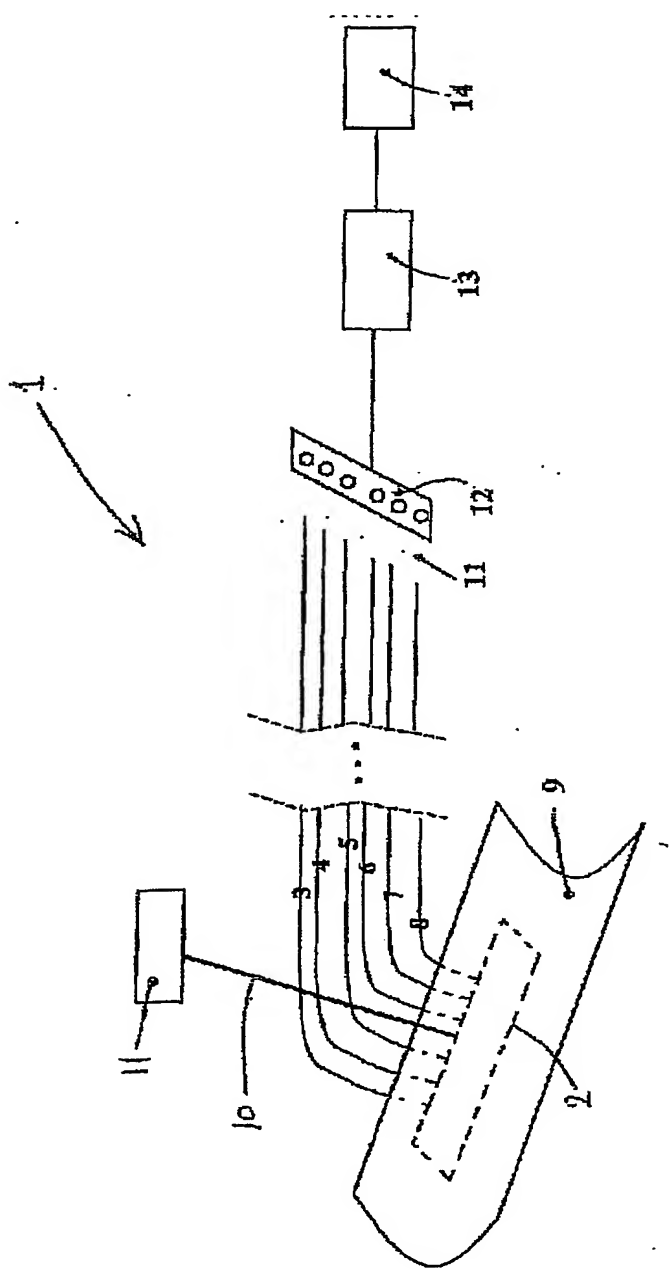
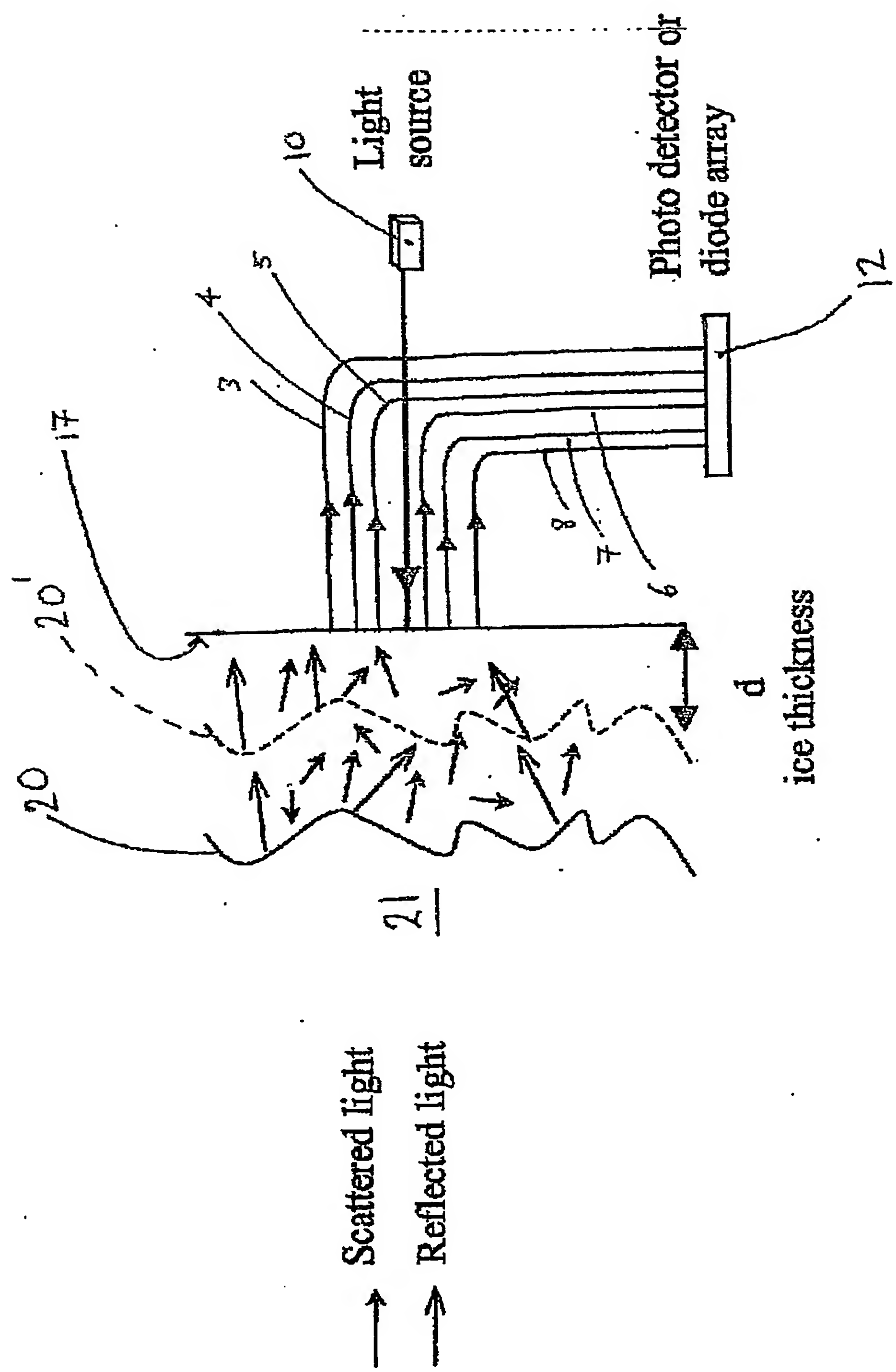



FIGURE 1



Light source
10
5
4
3
17
20'
20
21
Photo detector or diode array
12
8
7
6
d
ice thickness
Scattered light
Reflected light


FIGURE 2

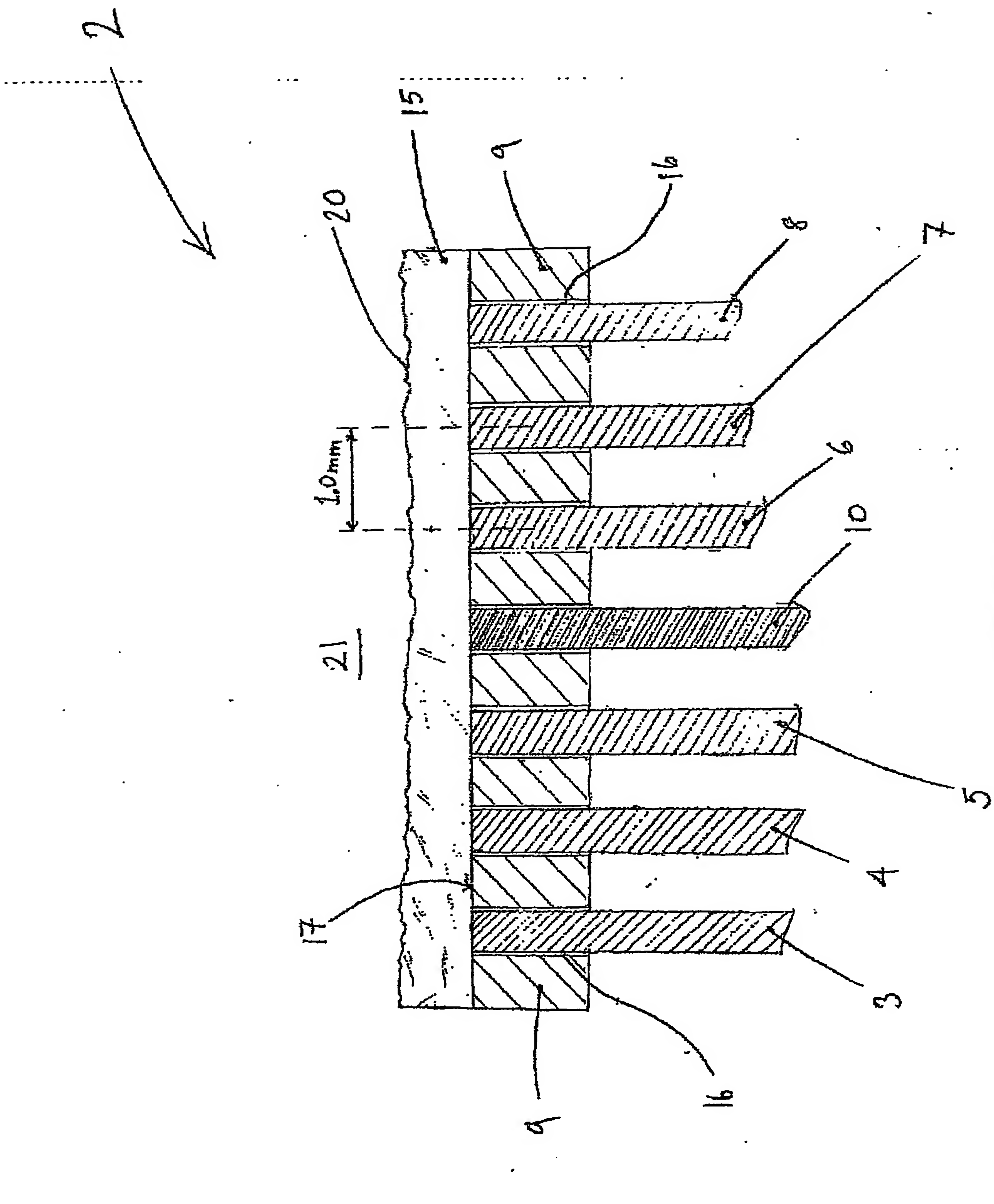



FIGURE 3

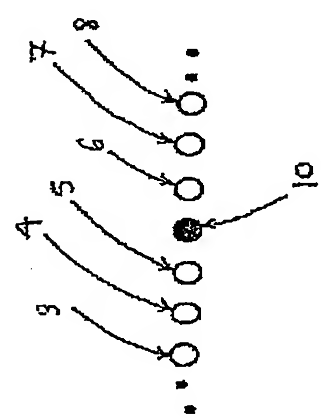



FIGURE 4

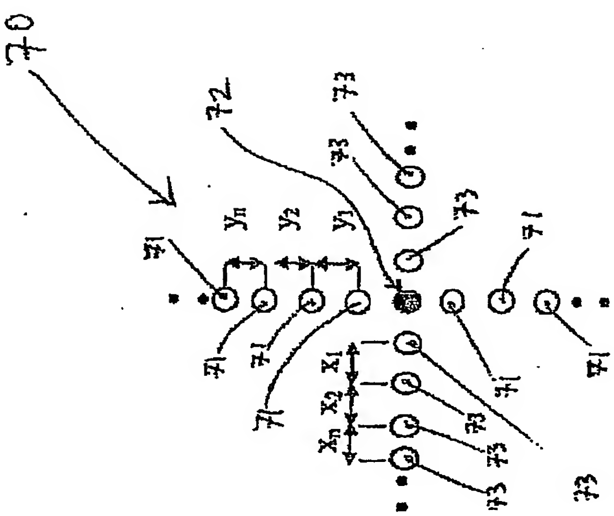



FIGURE 5

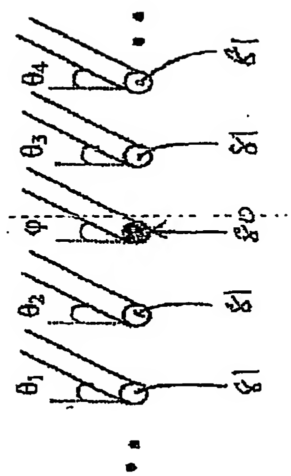



FIGURE 6

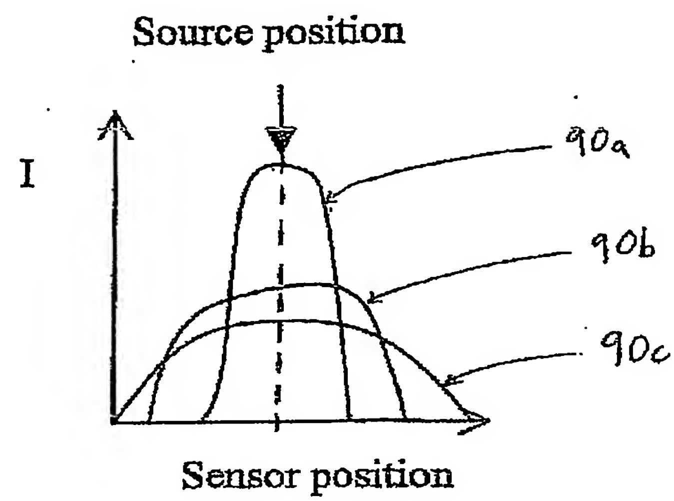



FIGURE 7

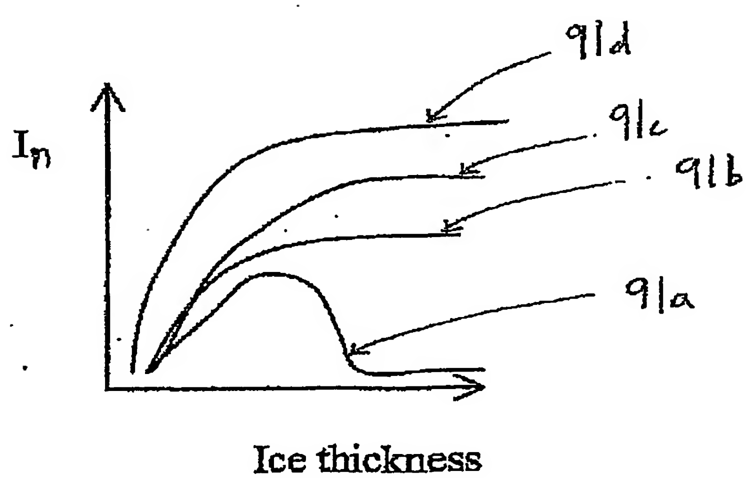



FIGURE 8

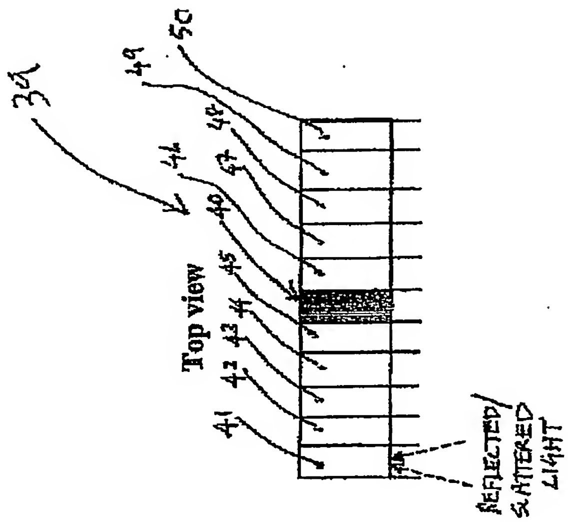



FIGURE 10

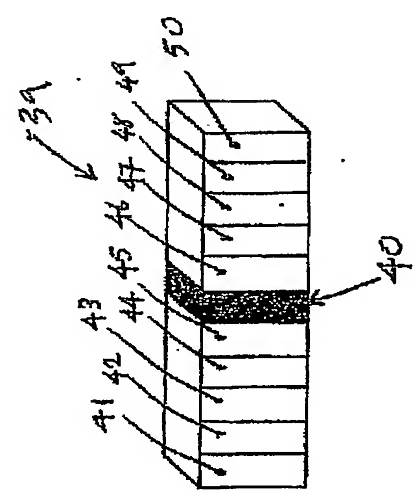



FIGURE 9

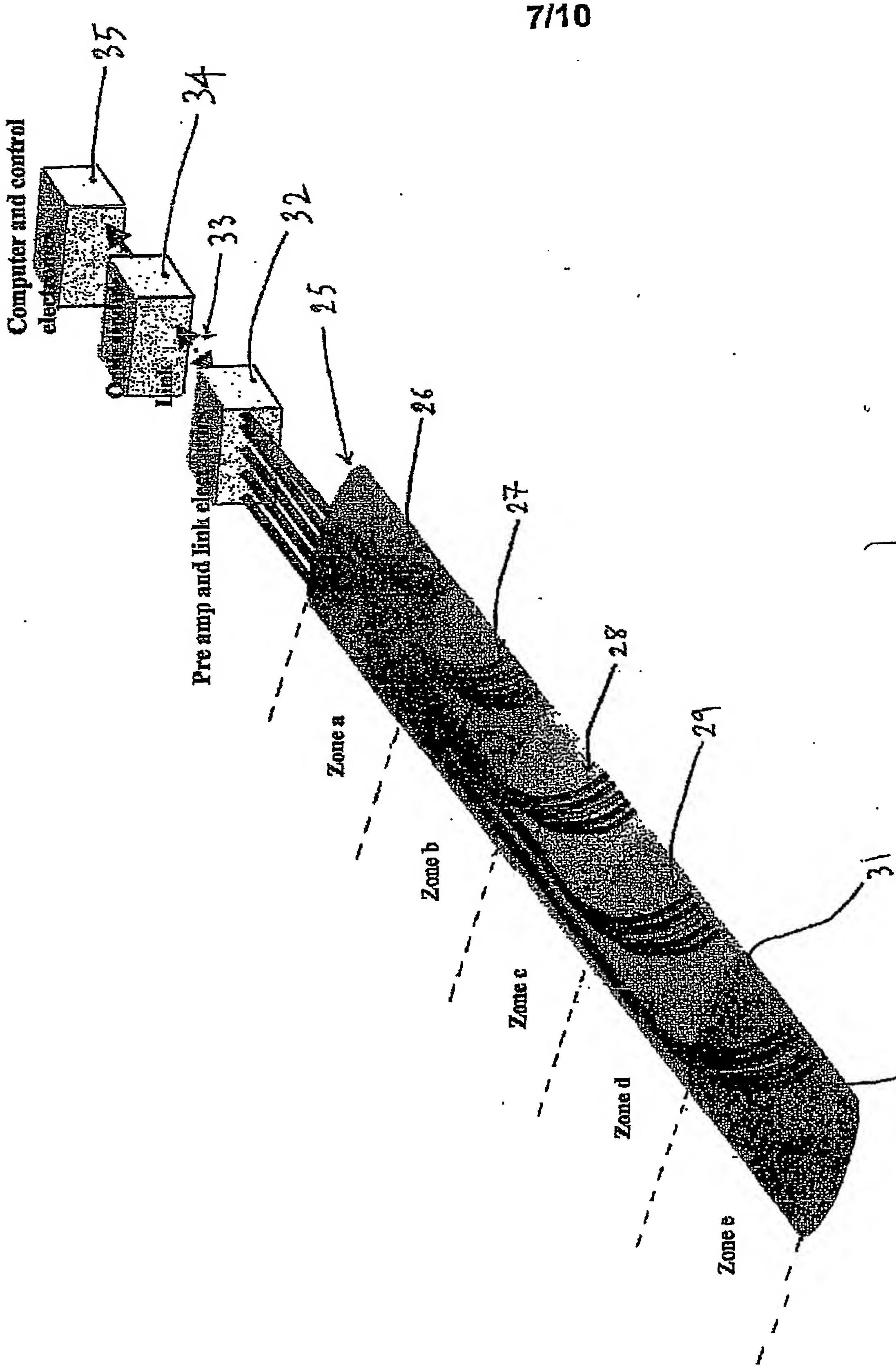
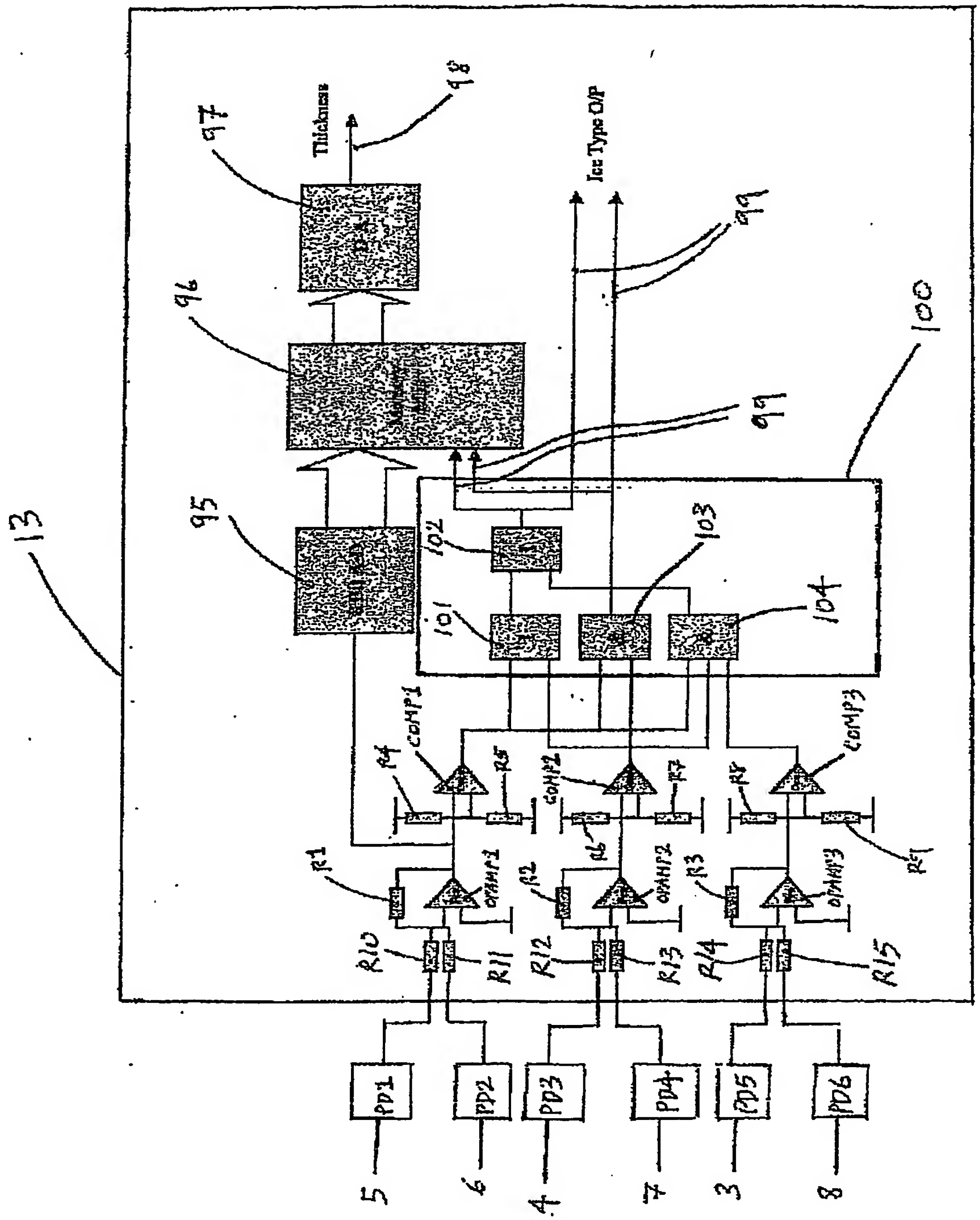

Computer and control
Pre amp and link
35
34
33
32
25
26
27
28
29
31
30
Zone a
Zone b
Zone c
Zone d
Zone e

FIGURE 11



Thickness
Ice Type O/P
13
95
96
97
98
99
99
100
101
102
103
104
COMP1
COMP2
COMP3
OPAMP1
OPAMP2
OPAMP3
R1
R2
R3
R4
R5
R6
R7
R8
R9
R10
R11
R12
R13
R14
R15
PD1
PD2
PD3
PD4
PD5
PD6
5
6
4
7
3
8


FIGURE 12

| Comp1 | Comp2 | Comp3 | O/P |
|---|---|---|---|
| 0 | 0 | 0 | 00 |
| 1 | 0 | 0 | 01 |
| 1 | 1 | 0 | 10 |
| 1 | 1 | 1 | 11 |

FIGURE 13

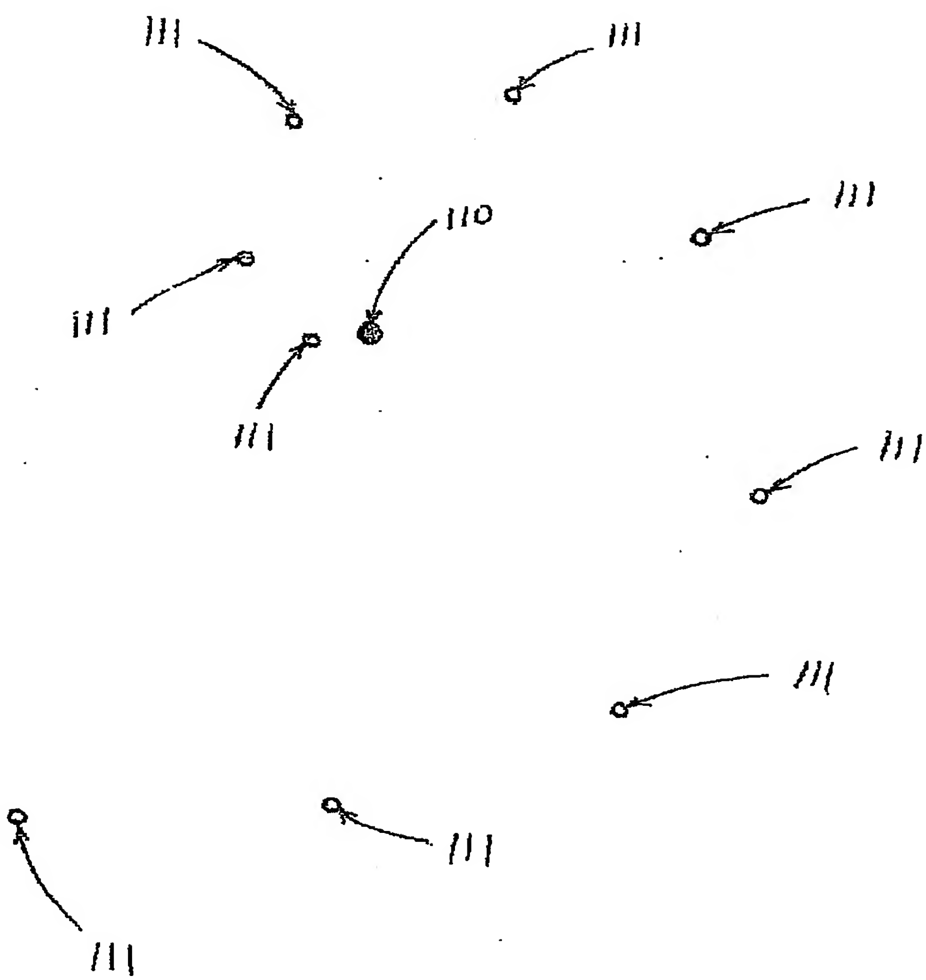



FIGURE 14